UCRL-PROC-212998

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June 16, 2005

8th International Workshop on Fast Ignition of Fusion Targets
Tarragona, Spain
June 27, 2005 through July 1, 2005

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LSP Calculations of Cone-Wire Experiments

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Recent experiments at the Institute of Laser Engineering (ILE) in Japan [1] and at Rutherford Appleton Laboratory (RAL) in the United Kingdom [2] have shown good coupling of short-pulse high-intensity laser light into high-energy electrons channeled down a narrow fiber. Such target configurations are being considered as backlighter targets on the National Ignition Facility (NIF). We will report on LSP calculations of these cone-wire experiments and other candidate target configurations. These calculations also give insight into the transport of MeV-electrons, which remains the critical issue for the achievement of fast ignition [3]. The LSP code uses a direct implicit particle-in-cell (PIC) algorithm in 2 or 3 dimensions to solve for beam particle transport, while treating the background particles as a fluid [4]. We have modified LSP to produce Kα photons in a non-interfering manner and will show calculated absolute Kα yields for the experiments reported by Key [2].

Backlit X-ray radiography has been a mainstay of experimental laser-plasma research for many years. It has been extensively used to diagnose and image planar and convergent geometry hydrodynamic experiments on laser facilities such as Nova and OMEGA. However, future facilities, such as the National Ignition Facility, have considerably more laser energy and are thus capable of driving larger targets to higher densities than previously possible. These targets have large areal densities that render them opaque to the relatively low energy x rays that have been routinely used in the past and require us to examine x rays in the 20 to 200 keV range. Unfortunately, the x-ray production efficiency using traditional thermal sources is extremely low at these energies and thus makes them prohibitively expensive. It has long been known that short-pulse high-intensity lasers interacting with dense targets create hard x-ray radiation with relatively high efficiency. A number of laboratories around the world are adding such high-intensity lasers to their existing compression facilities and hence there is considerable interest in optimizing the design of these short-pulse sources. In particular, developing high brightness, compact (~10 μm) one- and two-dimensional sources have been the subject of recent Petawatt experimental campaigns at the RAL.

When a short-pulse high-intensity laser interacts with a solid density target the laser accelerates electrons to relativistic energies. These electrons travel through the bulk of the target, interacting with the background ions to generate Kα fluorescence emission. By appropriate choice of fluor material it is possible to generate a quasi-monoenergetic source of the appropriate energy. Ultimately x rays in the 20 to 200 keV range are required, however for most of the experiments to date the fluor material has been copper, which generate 8.0 keV Kα photons, although it should be noted that samarium targets (which generate 40 keV Kα photons) have also been shot [5].

In order to model these experiments we have used the LSP code originally developed by Mission Research Corporation for use in the ion beam fusion community. LSP is a fully three dimensional hybrid-PIC code capable of running in Cartesian or cylindrical geometries. It employs a direct implicit particle push (based on the algorithms developed by Friedman, Hewett, Langdon and Cohen [6]). This algorithm enables larger time steps than conventional explicit PIC codes, which must operate on space and time scales given by the Debye length and plasma frequency, allowing solid density, colder plasmas to be modeled. Such plasmas are more collisional and so LSP incorporates inter- and intra-species collisions based on Spitzer collision frequencies. Finally electrons can be represented as kinetic, or fluid particles. In the fluid description the electrons carry a temperature, which is advanced by a separate energy equation that greatly reduces the effect of numerical cooling. The net effect of these algorithms is to enable LSP to model larger, more dense transport-region plasmas for longer simulation times than explicit PIC codes.

One of the cone-wire targets that were recently shot at RAL is a good example of the problem sizes that can be modeled. The target consists of a 200-μm long 10-μm radius copper wire embedded in a 30° full angle 10-μm thick, 250-μm long aluminum cone. An ionization state of +2 and +3 for the copper and aluminum were used throughout the simulation.

Rather than model the laser-plasma interaction within the same simulation we have applied scaling laws derived from small-scale explicit PIC simulations and experimental data to establish the hot electron parameters from the incident laser intensity. For the RAL Petawatt laser conditions, (300J delivered on target in a 0.5-ps pulse) we estimate an overall 30% conversion efficiency into hot electrons. This translates into the promotion of approximately

3×10^{14} electrons with an average energy of 1.7 MeV within a 10-μm fwhm spot (more details can be found in reference [7]).

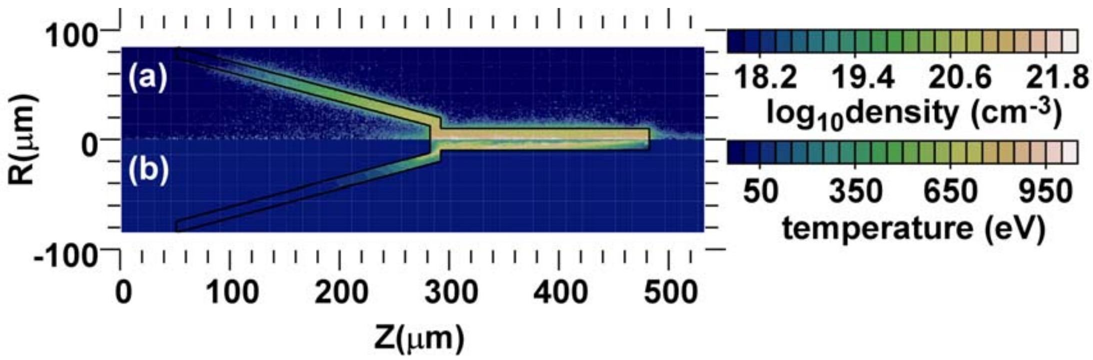

Figure 1: Color contour plot of the (a) hot electron number density and (b) background fluid electron temperature at 1.0 ps.

In the original version of LSP, a medium model needed to be inserted into the plasma target in order to generate photons. The transport of electrons in this medium model then used the physics kernel of the Integrated Tiger Series (ITS) codes [8]. This model does not allow ions to penetrate or allow electrons to be confined by their self-generated fields. We modified LSP so that the only effect of calling the medium model was to record the photon birth-position. These photons can then be transported using ITS to generate simulated images for comparison with experiments.

Figure 1a shows the hot electron beam density at 1.0-ps on a logarithmic scale. The hot electrons are promoted from the background fluid electrons at the left-hand edge of the cone tip in a depth of 3 μm. The highest number density occurs around this promotion region. This intense electron beam travels through the dense cold background plasma drawing a return current that largely compensates the forward going current. The beam is subject to the filamentary instability as can be seen in the short-wavelength structure in the beam. These electrons generate photons whose spectra are shown in Figure 2a. Clearly visible above the background bremsstrahlung radiation is the cold copper Kα and Kβ lines at 8.0 and 8.9 keV. Examining the birth position of the Kα photons in Figure 2b we see the highest concentration of photons near the promotion region and then a relatively constant amount along the length of the wire with a slight increase at the tip of the wire, which is in reasonable agreement with the experimental data. It should be noted that the ITS model uses cold cross-sections, however Figure 1b shows that the background electron temperatures reaches 1-keV along the wire which is more than sufficient to move the line outside the energy window of the crystal imager used on the experiment. A more detailed atomic physics model (incorporating such thermal shifts) is being added to LSP.

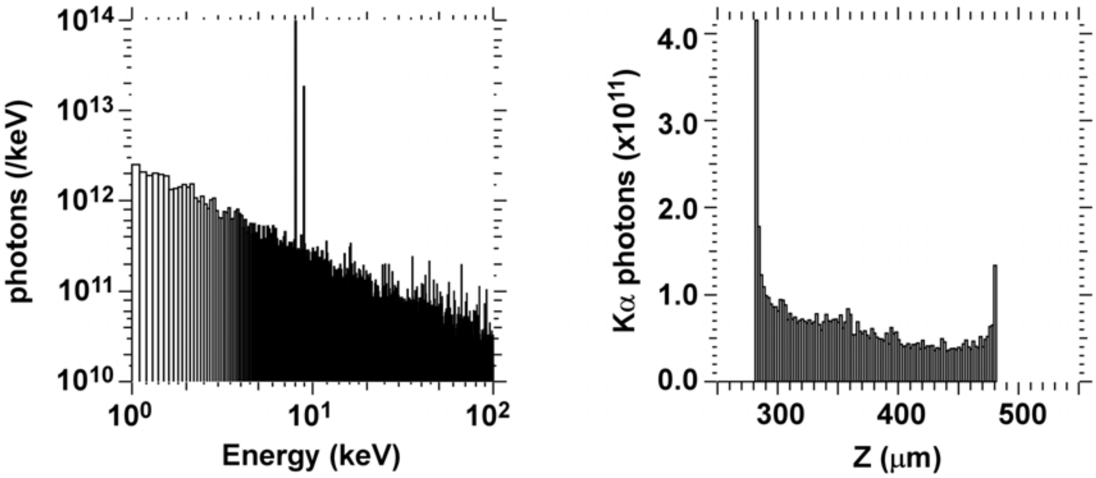

Figure 2: The time integrated (a) emission spectrum and (b) distribution of Kα photons along the wire length.

ACKNOWLEDGEMENTS

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48. UCRL-PROC-212998

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